Littoral Subsonic Seismoacoustic Phenomena Ultrasonic Modeling

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LONG-TERM GOALS

Develop comprehensive physical understanding of fundamental littoral subsonic seismoacoustic phenomena on the interaction of broadband transient underwater acoustic waves, interface Scholte waves , and surface Rayleigh waves with naturally-deposited /disturbed heterogeneous marine sediments with topography, variable water/air content, and benthic shelled animals leading to accurate acoustic modeling of littoral surficial layer and geophysical inversion needed for reliable seismoacoustic detection of buried objects in very shallow water and the unsaturated surf zone.

OBJECTIVES

Identify physical mechanisms contributing to subcritical sound penetration, conversion, propagation, and scattering of underwater acoustic waves and Scholte waves in disturbed and naturally deposited sandy sediments. Characterize frequency-dependent phenomena associated with the interaction of broadband transient Scholte and Rayleigh waves with heterogeneous sediments and sand ripples with at least one dimension comparable to the wavelength. Identify and characterize different types of seismoacoustic waves existing in water-saturated sand and unsaturated sand in various forms (naturally deposited, disturbed, compacted, and liquefied). Contribute to the understanding of seismoacoustic phenomena associated with benthic shelled animals (sand dollar).

APPROACH

Ultrasonic modeling techniques developed by Chamuel [1-7] since 1979 are used to obtain qualitative and quantitative experimental results under controlled laboratory conditions to characterize wave penetration, conversion, dispersion, and scattering. These ultrasonic modeling techniques proved to be cost-effective powerful tools complementing numerical methods and field experiments by providing physical insight into complex broadband seismoacoustic wave phenomena [1-7].

WORK COMPLETED

Provided a new hypothesis [6] explaining the anomalous acoustic slow wave [8] detected in underwater sand. Obtained ultrasonic modeling results on the conversion of near-grazing refracted waves in an inhomogeneous medium with depth-dependent elastic properties. Conducted small-scale controlled laboratory experiments to study the seismoacoustic characteristics of various wet sand conditions depending on granular properties, settling rate, vibration, mixing, liquefaction, compaction, drainage history, and water level. Recorded compressional, shear, Rayleigh, and

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Scholte waves data to determine variations in wave velocity and attenuation depending on sand conditions and history. Characterized the effect of water level in sand on surface Rayleigh waves. Characterized Bragg frequency interface wave dispersion by sand ripples. Identified and characterized a new transmission loss mechanism by demonstrating the generation of shear waves in seabed at all scales from the conversion of interface waves by the edge of localized fluidized regions in the absence of sediment topography. Measured and compared the elastic properties of different sand dollar skeletons (Fig. 6).

RESULTS

Observed new seismoacoustic characteristics of water-covered sand disturbed sand (Fig. 1-5) demonstrating that the elastic properties of wet sand greatly depend on sand condition and history [7]. One of the findings was that the shear wave velocity and amplitude remained practically unchanged while the high-frequency compressional wave was highly attenuated in certain disturbed sand. The results indicate that the ratio of Rayleigh wave velocity to shear wave velocity varied as the water level changed (Fig. 5). As the water level rised, the Rayleigh wave velocity of the low-frequency components decreased before the high-frequency Rayleigh waves (Fig. 5). Characterized the dispersion of Scholte waves propagating along a rippled surface of an immersed "soft" solid half-space. The findings revealed that a rippled "soft" liquid/solid interface can decrease the velocity of high-frequency Scholte wave components propagating normal to the ripples by more than 70% [5]. The findings are essential for inverting geophysical properties from Scholte wave data to separate the effect of layering and roughness. A new hypothesis was given [6] explaining the anomalous ultrasonic slow wave [8] detected in underwater sand using a layered elastic model. The new hypothesis provided a another explanation for the time of arrival of the observed anomalous slow wave without contradicting the well established Biot parameters for water-saturated sand, and also provided an explanation for the other multiple features (believed to be artifacts) existing in the actual sediment acoustic data [8]. Studies on relative amplitudes of refracted waves in sediments led to investigating the seismoacoutic properties of various forms of water-covered sand. Obtained experimental results demonstrating that only one interface Scholte wave exists along a liquid/solid interface with no other coexisting Rayleigh wave, contradicting the results of Padilla et al. [11], where the shear wave velocity of the solid is smaller than the fluid compressional wave velocity (as in most seabed sediments). The findings are significant for interpreting the roots of the Scholte wave dispersion equation and understanding energy partitioning. Obtained the first experimental results characterizing nondispersive antisymmetric flexural wedge waves along sand dollar skeletal edge (Fig. 6). Measured and compared the elastic properties of different sand dollar skeletons with the same age (Fig. 6). Their elastic properties and wave velocities were nearly identical. This is important because sand dollar beds may be dominated by a single age group affecting the interaction of acoustic waves.

IMPACT/APPLICATIONS

Achieve better physical understanding of fundamental littoral seismoacoustic phenomena on the interaction of underwater acoustic waves with marine sediments leading to accurate acoustic modeling of littoral surficial layer and geophysical inversion important for reliable seismoacoustic detection of buried objects.

Applications include interpretation of sediment seismoacoustic data, inversion of geoacoustic data based on Scholte wave characteristics, development of interface wave seismoacoustic sonar, evaluation of stability of sand core samples for microfabric studies, determination of effect of shelled animals on seabed properties, and detection of buried objects.

TRANSITIONS

The research outcome would affect the planning of future shallow water field experiments and interpretation of seismoacoustic data leading to accurate seabed characterization and reliable acoustic detection of buried objects. Further research is needed to determine the seismoacoustic properties of various sand conditions.

RELATED PROJECTS

The work relates to several sponsored ONR research projects and more specifically the Departmental Research Initiative program on High-Frequency Sound Interaction in Ocean Sediments and ASIAEx bottom interaction studies. The research is related to efforts on rough interface scattering, ocean bottom penetration, geoacoustic inversion, sediment characterization, seismic sonar, detection of buried objects, surfseisms, air bubbles in sediments, marine biology, and hydroacoustics (N. P. Chotiros, R. D. Stoll, E. I. Thorsos, D. R. Jackson, A. N. Ivakin, K. Williams, H. Simpson, M. Richardson, R. Stoll, M. Buckingham, T. Muir, E. Smith, J. Lopes, G. D'Spain, D. Bibee, D. Velea, J. M. Sabatier, D. H. Berman, G. B. Deane, V. Holliday, P. Jumars, R. Lim, R. A. Stephen, and P. Kackzkowski).

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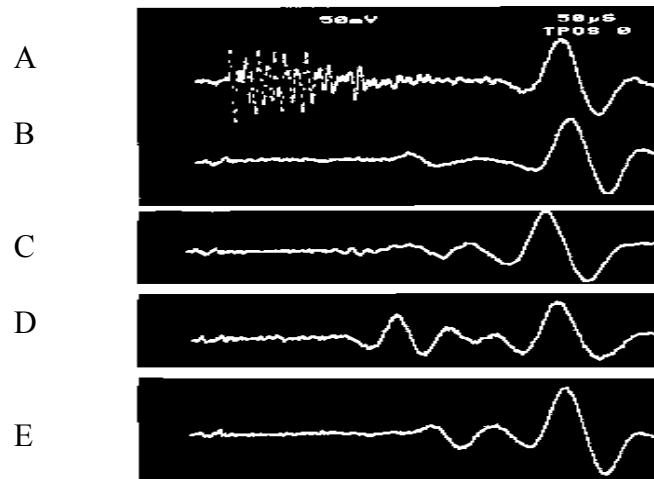
Fig. 1.   Waveform variations in water-covered sand: (A) naturally deposited sand, (B-E) water-covered disturbed sand (when water level was below sand). Notice presence of a high-frequency fast compressional wave 1650 m/s in (A) followed by a low-frequency shear wave 140 m/s. The fast compressional wave was highly attenuated in disturbed sand while the shear wave was practically not affected. A new slow compressional wave appeared in water-covered disturbed sand 190-400 m/s.


Drained Wet Sand
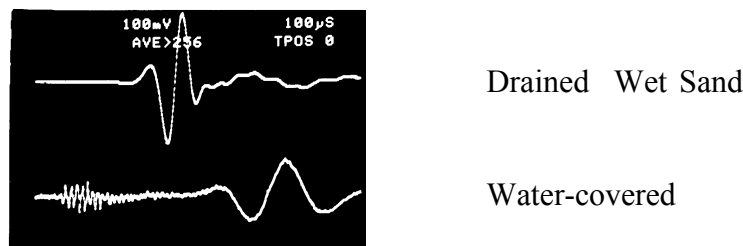
Water-covered

Fig. 2. Comparison of compressional waves in drained wet sand and water-covered sand. The top trace shows a slow ~10 Khz pulse compressional wave (190 m/s). The bottom trace shows two compressional waves: one fast high frequency compressional wave, and one slow low-frequency wave (faster than the shear wave). The source was excited with one broadband pulse. The coexistence of the fast and slow compressional waves has been elusive depending on sand conditions.
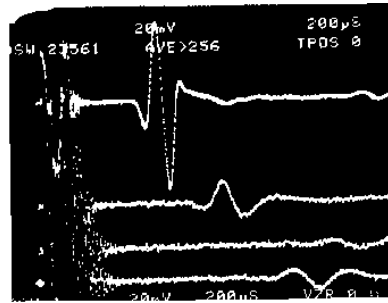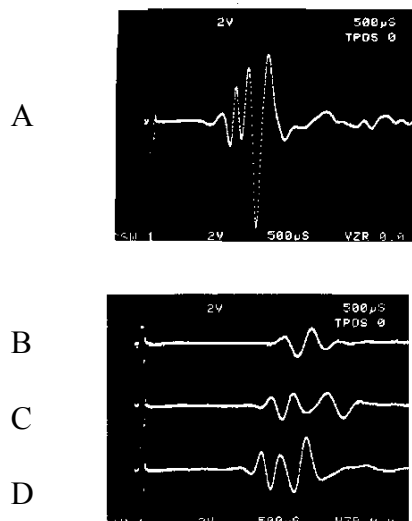
* Drained Sand

* Water-Covered
* Liquefied
* Compacted

Fig. 3. Variations of shear wave amplitude and arrival time in naturally deposited underwater sand due to liquefaction and compactness. The high-frequency components at the beginning of the traces are due to compressional waves. Notice shear wave velocity decreased with liquefaction and water loading.
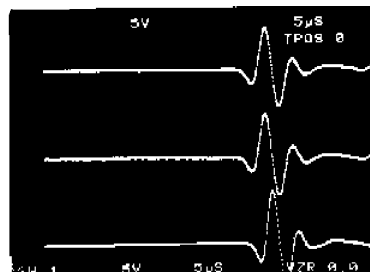
Water-Covered
Naturally Deposited Sand (1610 m/s)

Dropped Water Level 9 cm Below Sand

Water-Covered Liquefied Sand (1556 m/s)

Fig. 4. Comparison of high-frequency compressional wave in sand. Compressional wave velocity dropped from 1610 m/s to 1556 m/s with liquefaction. Compressional wave attenuation decreased in liquefied sand.

A

Drained Wet Sand
$C_{rayleigh}$= 65 m/s

Water Level
below sand surface
B   0 cm

C   1.5 cm

D   3 cm

Fig. 5. Effect of water level in sand on Rayleigh and shear waves. Water saturation decreased the Rayleigh wave velocity from 65 m/s to 44 m/s. Notice as the water level dropped 3 cm below the sand (Trace D), the Rayleigh wave amplitude (high right peak) increased and its propagation time decreased. The ratio of shear wave velocity to Rayleigh wave velocity varied as the water level changed.
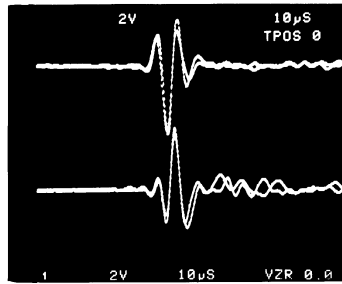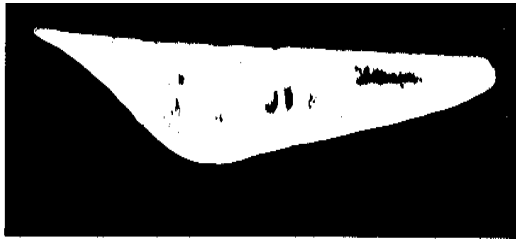
Thick Section

Thin Section

Fig. 6. Sand dollar cross section showing wedge geometry with variable apex angle. Superimposed waveforms of antisymmetric edge waves from two different sand dollars with same size demonstrating close similarity between their elastic properties. Wedge waves along thick and thin edge portions of sand dollar.